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Modelling visual performance in luminescent solar concentrators

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Introduction

- Increased interest for building integrated photovoltaics (BIPV)
- Aesthetics, freedom of form and color
- Luminescent solar concentrators are good BIPV candidate
- Transparent windows: visual comfort and well-being of the occupants of the building

Color

- Prediction of color required
- Calculate CIE chromaticity diagram [3], correlated color temperature (CCT) and color render index (CRI) based on absorption and emission spectra of luminophores

Potential use

Restaurant, café

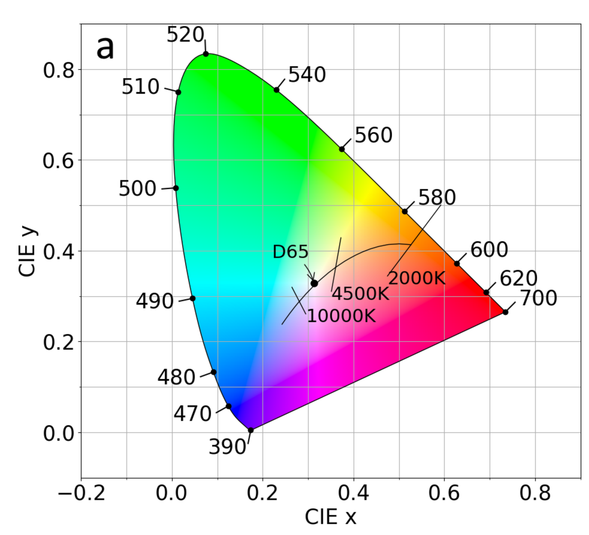
Bus shelter

Aim

- Predict color of LSC device with different luminophores
- Use nanocrystals as luminophores [1]

Method

- Ray trace simulation, `pvtrace` [2]
- LSC size 10x10x0.5 cm^3, with 8 different luminophores
- 1 million photons from AM1.5 spectrum
- Transmitted spectrum is modified AM1.5, depending on absorption of luminophore, $P(\lambda)$
- Calculate CIE chromaticity diagram X, Y [3]



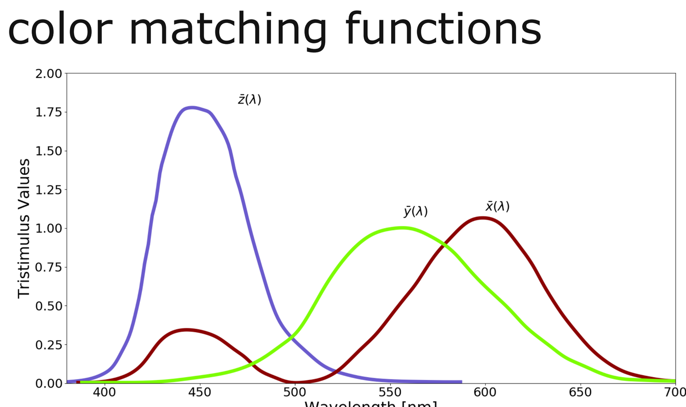
using

$$X = K\int_{vis} P(\lambda)\bar{x}(\lambda)d\lambda,$$

$$Y = K\int_{vis} P(\lambda)\bar{y}(\lambda)d\lambda,$$

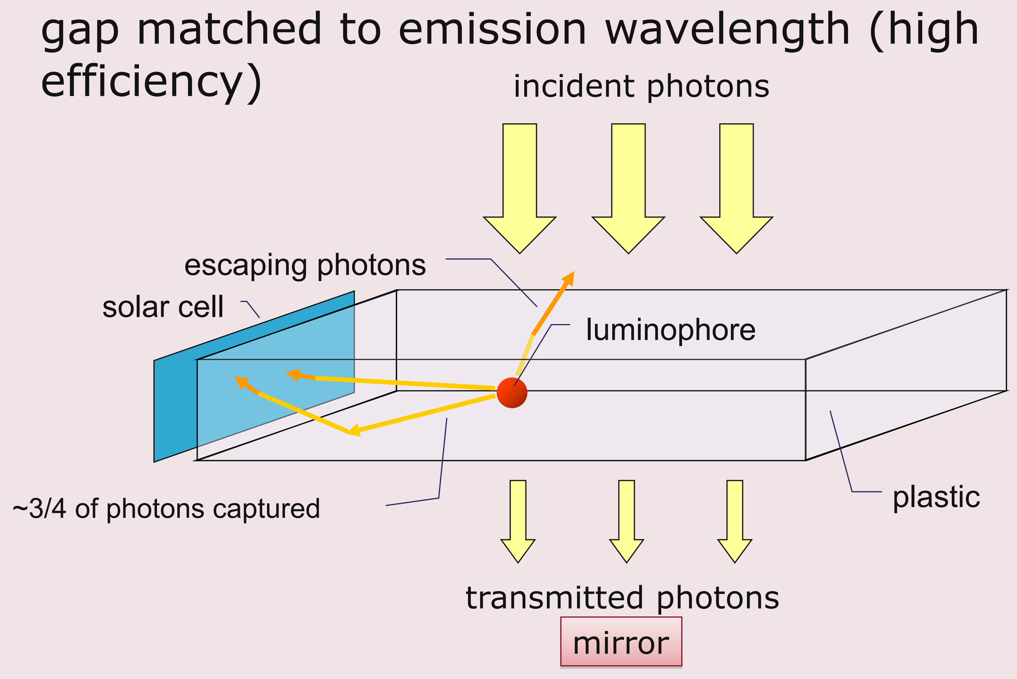
$$Z = K\int_{vis} P(\lambda)\bar{z}(\lambda)d\lambda,$$

with color matching functions



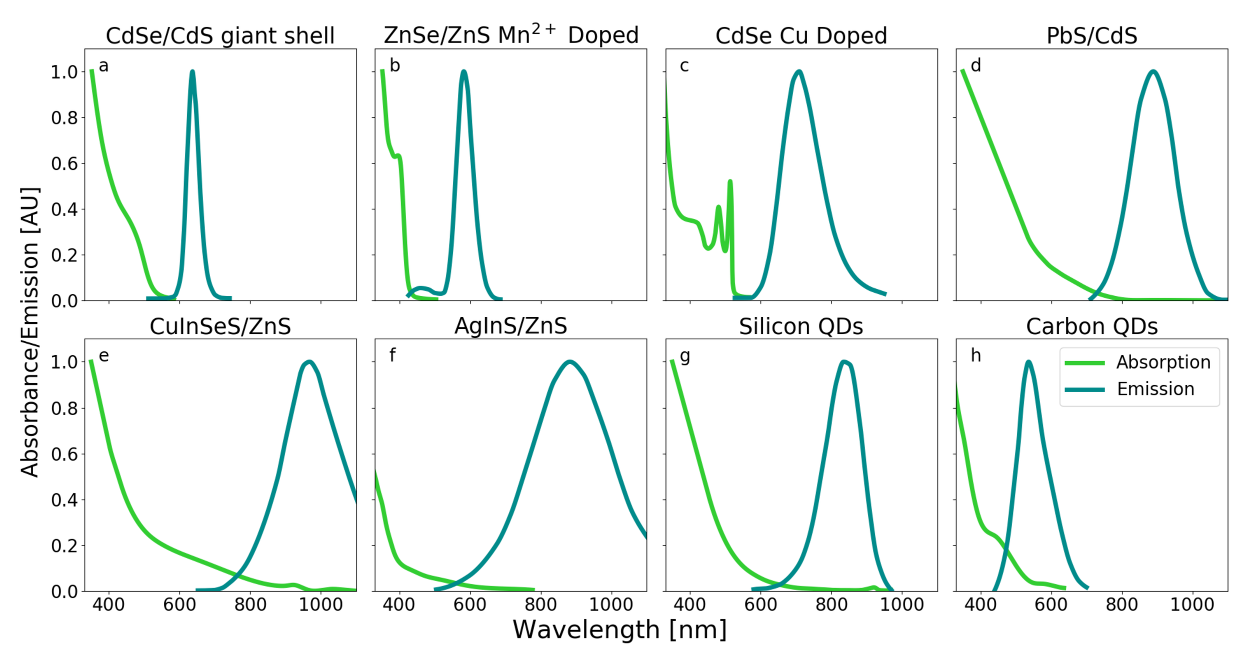
Luminescent Solar Concentrator principle

- Luminophores absorb photons and emit red-shifted photons
- Total internal reflection causes ¾ of emitted photons to remain in light guide
- Solar cells attached to sides, ideally with band gap matched to emission wavelength (high efficiency)



Luminophores

Luminophore	Emission peak (nm)	FWHM (nm)	Quantum Yield (%)
CdSe/CdS-giant shell	640	60	45
ZnSe/ZnS Mn^{2+} doped	590	80	50
CdSe Cu doped	705	110	70
PbS/CdS	890	160	50
CuInSeS/ZnS	960	180	40
AgInS/ZnS	900	290	30
Silicon QDs	830	120	45
Carbon QDs	550	110	40



Results

- Luminophores are located at different points on the chromaticity diagram
- Color temperature values are in accordance with the colors in the chromaticity diagram. The blue-colored PbS dots have a very high value: all other luminophores have a lower color temperature, ranging from 3,000-5,500 K, which corresponds to their red colors.
- Color rendering index is high for most samples, mostly above 85. Only PbS and Si chromophores have values below 80. This is consistent with the observation that these two types yield the strongest coloration in light.
- Low CRI values are the result of non-uniform absorption of the solar spectrum: luminophores that emit high energy photons (absorb more in the blue) have also lower CRI values

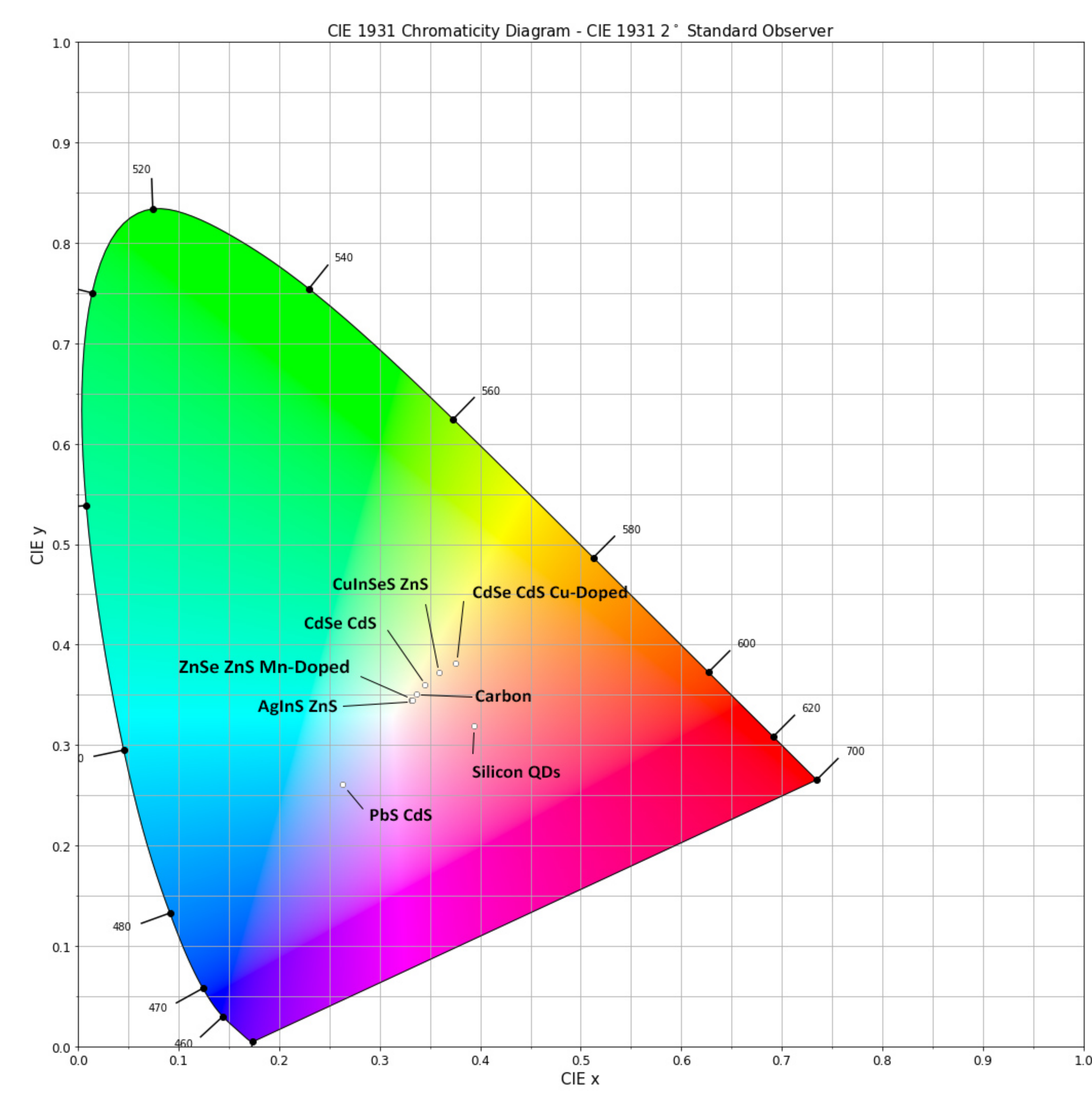
References

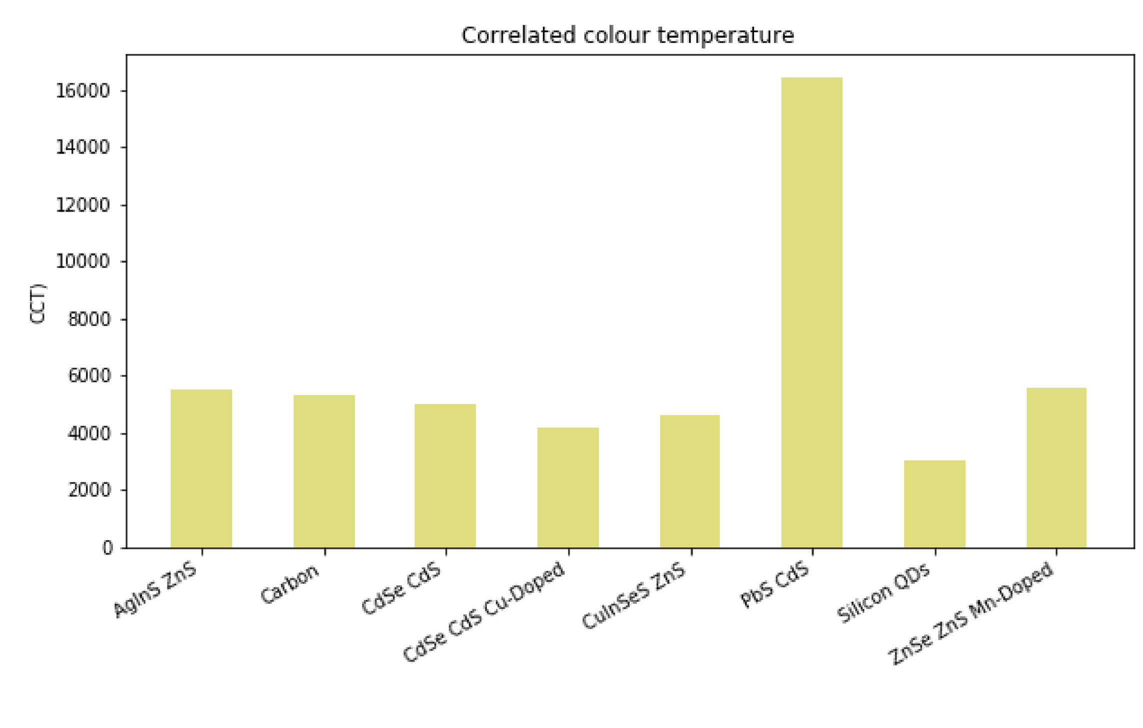
[1] P. Moraitis, R. Schropp, W. van Sark, "Nanoparticles for Luminescent Solar Concentrators—A review," Opt. Mater., vol. 84, pp. 636–645, 2018.

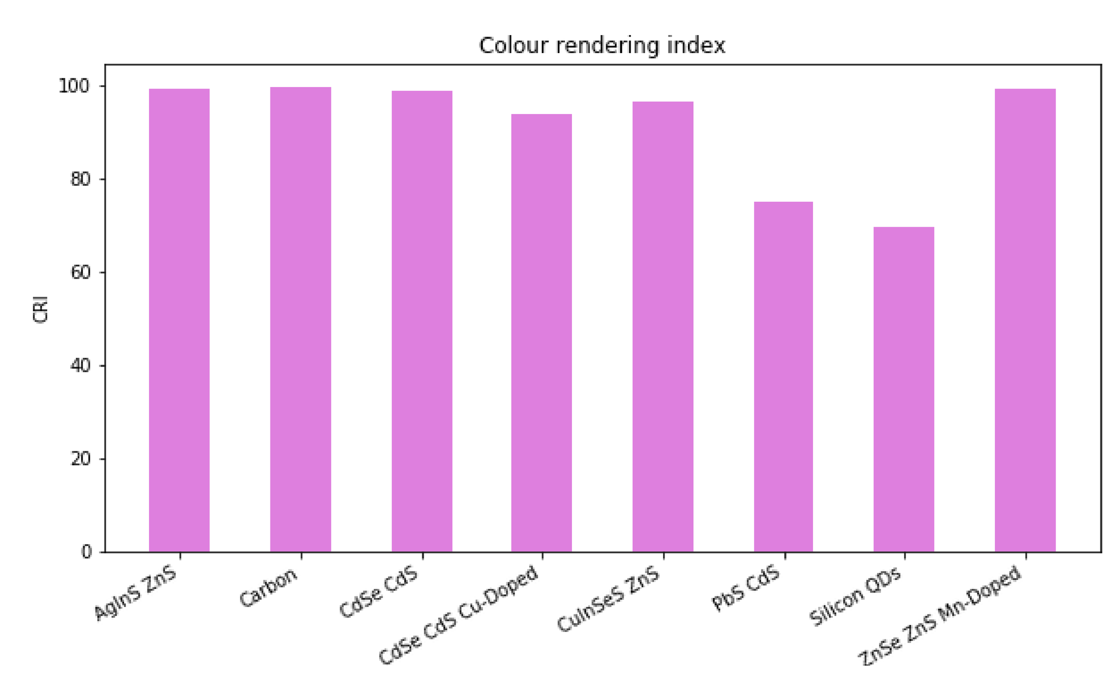
[2] D.J. Farrell, "pvtrace: optical ray tracing for photovoltaic devices and luminescent materials", 2014. dx.doi.org/10.5281/zenodo.12820

[3] Commission Internationale de l'Eclairage, "Method of Measuring and Specifying Colour Rendering Properties of Light Sources", CIE 013.3-1995, Vienna, Austria, 1995.

Results







Conclusion

- Visual aspects of LSC studied
- Most luminophores have low color temperature, and high color rendering index

Acknowledgements

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